

# NLO QCD fits to polarized DIS & SIDIS data

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Global Analysis Workshop, BNL October 8, 2007

## why spin?

- indispensable tool for unveiling hadron structure,
- spin & unexpected physics.

## why polarized DIS?

- historical benchmark for hadron structure,
- 90's experimental programs.

## why NLO QCD global fits?

- QCD improved description for spin dependent processes
- LO vs. NLO

## why polarized SIDIS?

- flavor and quark-antiquark discrimination,
- increasead statistics, new/forthcoming data
- sea quarks and flavor dependence in hadronization.

## what do we get from data?

- fits to inclusive/semi-inclusive polarized data.
- uncertainties in pPDFs:  $\_q$ ,  $\_g$ .
- impact “direct”  $\_g$  measurements.

## how can we improve the present picture?

- further constraints from forthcoming data.
- fragmentation functions.

## The case for pSIDIS: pDIS flavor decomposition

$$g_1^{p,n} = \left[ \pm \frac{1}{12} \Delta q_3 + \frac{1}{36} \Delta q_8 + \frac{1}{9} \Delta \Sigma \right] \otimes \left( 1 + \frac{\alpha_s}{2\pi} C_q \right) + \sum e_q^2 \frac{\alpha_s}{2\pi} C_g \otimes \Delta g$$

$$\Delta \Sigma = (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) + (\Delta s + \Delta \bar{s})$$

$$\Delta q_3 = (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d})$$

$$\Delta q_8 = (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) - 2 (\Delta s + \Delta \bar{s})$$

$$\Delta q_3 \sim g_1^p - g_1^n$$

$$\Delta q_8 \Delta \Sigma \Delta g \sim g_1^p + g_1^n$$

$$Q^2 \frac{d}{dQ^2} \begin{pmatrix} \Delta \Sigma \\ \Delta g \end{pmatrix} = \begin{pmatrix} \Delta P_{qq} & \Delta P_{qg} \\ \Delta P_{gq} & \Delta P_{gg} \end{pmatrix} \begin{pmatrix} \Delta \Sigma \\ \Delta g \end{pmatrix}$$

$$Q^2 \frac{d\Delta q_8}{dQ^2} = \Delta P_{qq} \Delta q_8$$

## The case for pSIDIS: Flavor decomposition in pSIDIS

$$g_1^{Nh} = \frac{1}{2} \Sigma e_q^2 \left\{ \Delta q D_q^h + \frac{\alpha_s}{2\pi} \left[ C_{qq} \otimes \Delta q \otimes D_q^h + C_{qg} \otimes \Delta q \otimes D_g^h \right. \right. \\ \left. \left. + C_{gq} \otimes \Delta g \otimes D_q^h \right] \right\}$$

$$|\pi^+ > = |u\bar{d} >$$

$$D_u^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} \equiv D_1^\pi$$

$$D_{\bar{u}}^{\pi^+} = D_d^{\pi^+} = D_{\bar{d}}^{\pi^-} = D_u^{\pi^-} \equiv D_2^\pi$$

$$D_s^{\pi^+} = D_s^{\pi^-} \equiv D_s^\pi$$

$$2g_1^{p\pi^{+(-)}} \sim \frac{4}{9} (\Delta u + \Delta \bar{u}) D_{1(2)}^\pi + \frac{1}{9} (\Delta d + \Delta \bar{d}) D_{2(1)}^\pi + \\ \frac{1}{9} (\Delta \bar{d} - 4\Delta \bar{u}) (D_{1(2)}^\pi - D_{2(1)}^\pi) + \frac{1}{9} (\Delta s + \Delta \bar{s}) D_s^\pi + \mathcal{O}(\alpha_s)$$

$\Rightarrow \Delta \bar{u}, \Delta \bar{d}$

$\Rightarrow \Delta u_V, \Delta d_V$

$\Rightarrow$  corroborate  $(\Delta u + \Delta \bar{u}), (\Delta d + \Delta \bar{d})$  and  $(\Delta s + \Delta \bar{s})$

# DNS NLO combined analysis: parameterizations

D. de Florian, G. Navarro , R.S. Phys.Rev.D71 094018 (2005)

pDIS can probe:

$$x(\Delta q + \Delta \bar{q}) = N_q \frac{x^{\alpha_q}(1-x)^{\beta_q}(1+\gamma_q x^{\delta_q})}{B(\alpha_q+1, \beta_q+1) + \gamma_q B(\alpha_q+\delta_q+1, \beta_q+1)}, \quad q = u, d$$
$$x(\Delta s + \Delta \bar{s}) = 2N_s \frac{x^{\alpha_s}(1-x)^{\beta_s}}{B(\alpha_s+1, \beta_s+1)},$$
$$x\Delta g = N_g \frac{x^{\alpha_g}(1-x)^{\beta_g}}{B(\alpha_g+1, \beta_g+1)}.$$

$$N_u - N_d = (F + D)(1 + \epsilon_{Bj})$$

$$N_u + N_d - 4N_s = (3F - D)(1 + \epsilon_{SU(3)})$$

pSIDIS give access to:

$$x\Delta \bar{q} = N_{\bar{q}} \frac{x^{\alpha_{\bar{q}}}(1-x)^{\beta_{\bar{q}}}}{B(\alpha_{\bar{q}}+1, \beta_{\bar{q}}+1)}, \quad \bar{q} = \bar{u}, \bar{d}$$

→ 20 parameters

positivity relative to MRST02:  $|\Delta q| \leq q$

A.D. Martin et al. Eur.Phys.J.C28 (2002) 455

# DNS NLO combined analysis: data

Collaboration	Target	Final state	# points
EMC	proton	inclusive	10
SMC	proton,deuteron	inclusive	12, 12
E-143	proton,deuteron	inclusive	82, 82
E-155	proton,deuteron	inclusive	24, 24
Hermes	proton,deuteron,helium	inclusive	9, 9, 9
E-142	helium	inclusive	8
E-154	helium	inclusive	17
Hall A	helium	inclusive	3
COMPASS	deuteron	inclusive	12
SMC	proton,deuteron	$h^+, h^-$	24, 24
Hermes	proton,deuteron,helium	$h^+, h^-, \pi^+, \pi^-, K^+, K^-, K^T$	36,63,18
Total			478

$Q^2 > 1\text{GeV}^2$

## Fragmentation functions input in DNS:

KRE: S. Kretzer Phys.Rev.D62 054001 (2000)

KKP: B. A. Kniehl, G. Kramer, B. Potter, Nucl.Phys.B582 514 (2000)

flavor separation:

$$D_u^{\pi^+}(z, Q^2) = D_d^{\pi^+}(z, Q^2) = D_{\bar{u}}^{\pi^-}(z, Q^2) = D_{\bar{d}}^{\pi^-}(z, Q^2)$$

$$D_u^{\pi^+}(z, Q_0^2) = D_d^{\pi^+}(z, Q_0^2) = D_s^{\pi^+}(z, Q_0^2) = D_{\bar{s}}^{\pi^+}(z, Q_0^2) = D_s^{\pi^+}(z, Q_0^2) = (1-z) D_u^{\pi^+}(z, Q_0^2)$$

$$D_u^{K^+}(z, Q_0^2) = D_{\bar{u}}^{K^-}(z, Q_0^2) = (1-z) D_{\bar{s}}^{K^+}(z, Q_0^2)$$

$$D_d^{K^+}(z, Q_0^2) = D_{\bar{d}}^{K^+}(z, Q_0^2) = D_s^{K^+}(z, Q_0^2) = D_{\bar{s}}^{K^+}(z, Q_0^2) = (1-z)^2 D_{\bar{s}}^{K^+}(z, Q_0^2)$$

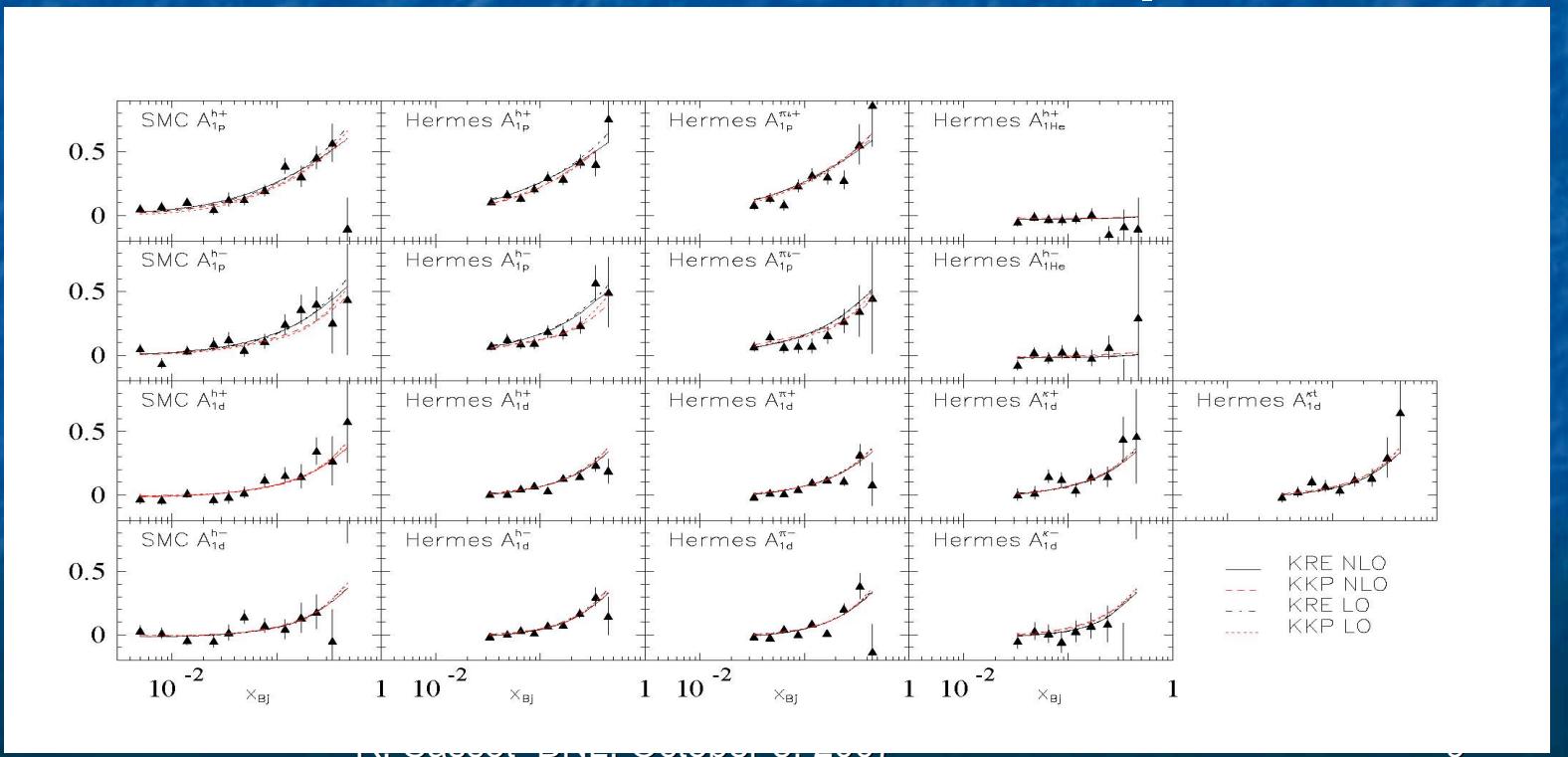
# DNS Results:

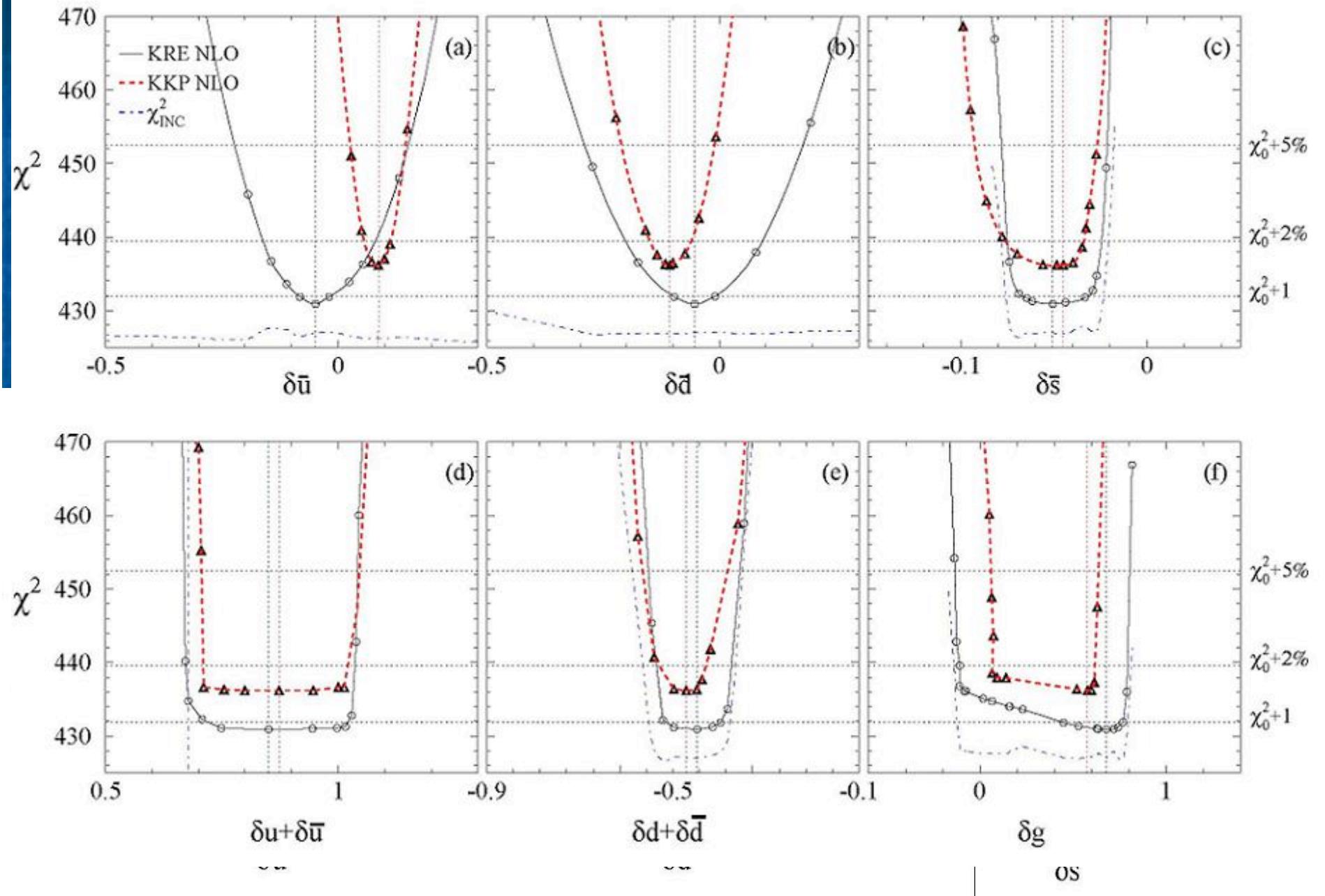


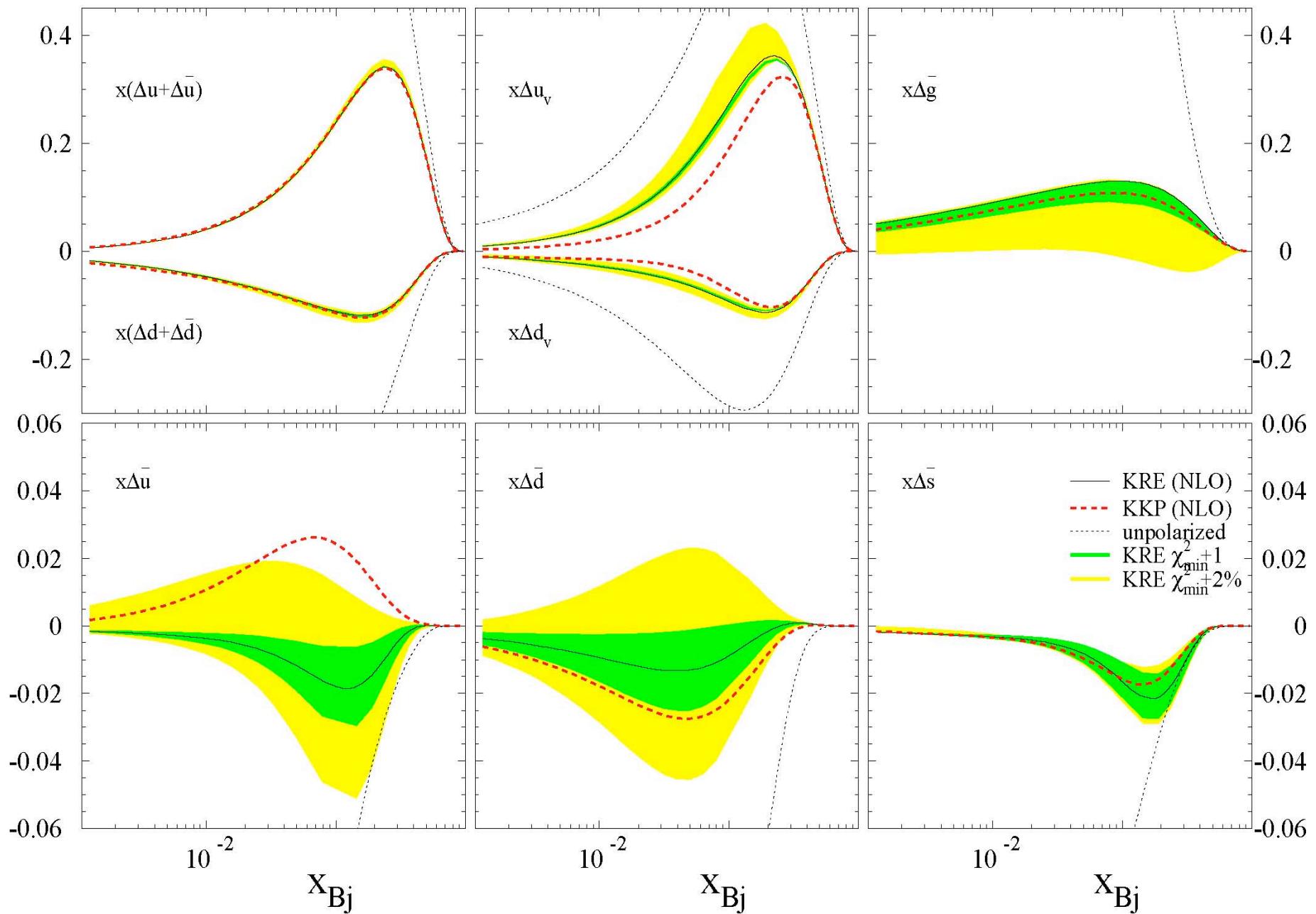
set	$\chi^2$	$\chi^2_{pDIS}$	$\chi^2_{pSIDIS}$	$\delta u_v$	$\delta d_v$	$\delta \bar{u}$	$\delta \bar{d}$	$\delta \bar{s}$	$\delta g$	$\delta \Sigma$	
NLO	KRE	430.91	206.01	224.90	0.936	-0.344	-0.0487	-0.0545	-0.0508	0.680	0.284
	KKP	436.17	205.66	230.51	0.700	-0.255	0.0866	-0.107	-0.0454	0.574	0.311
LO	KRE	457.54	213.48	244.06	0.697	-0.248	-0.0136	-0.0432	-0.0415	0.121	0.252
	KKP	448.71	219.72	228.99	0.555	-0.188	0.0497	-0.0608	-0.0365	0.187	0.271

478-20=458 d.o.f  
313 pDIS  
165 pSIDIS

$$\delta q \equiv \int_0^1 dx \Delta q \quad @ 10 \text{ GeV}^2$$

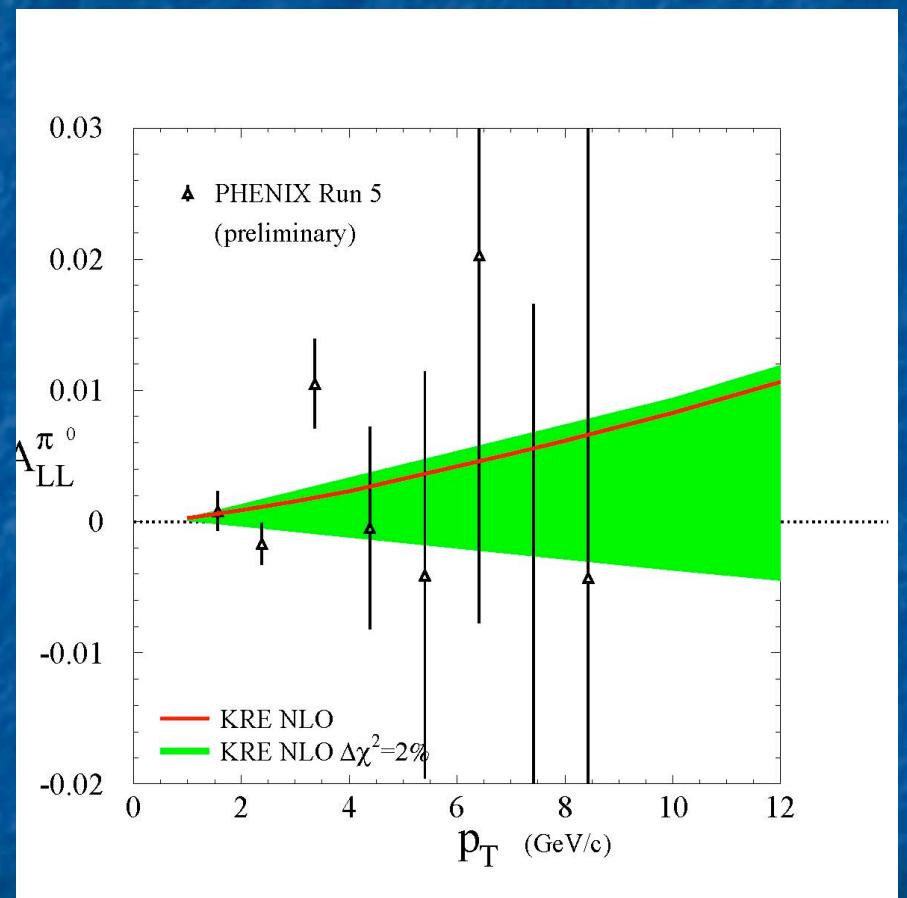
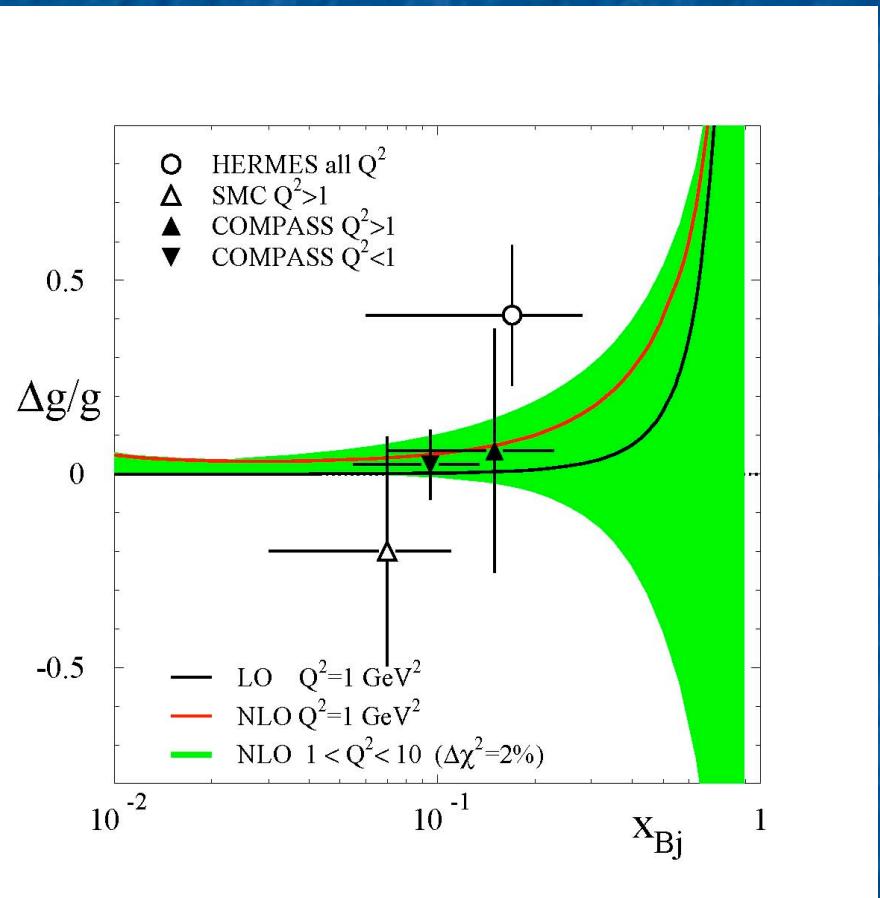




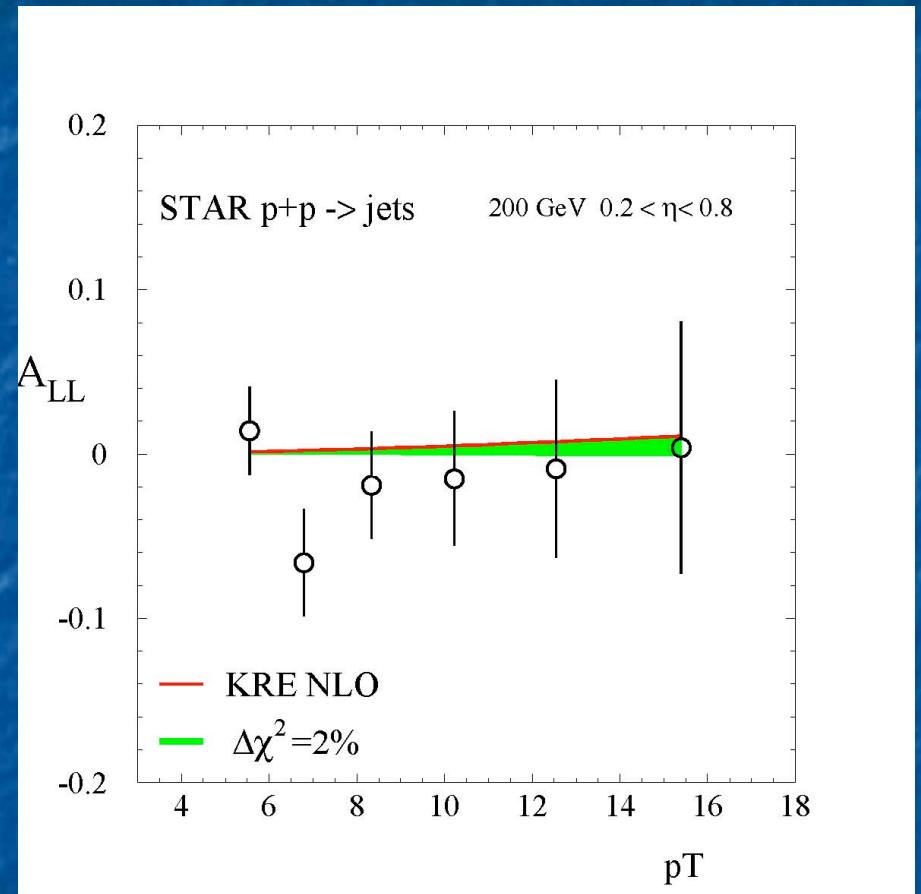


# Consistency with independent measurements:

G. Navarro , R.S. PRD74 011502 (2006)



STAR Coll., PRL97, 252001, (2006)



Next steps:

DSS FFs: kaon fragmentation,  $h^+/h^-$

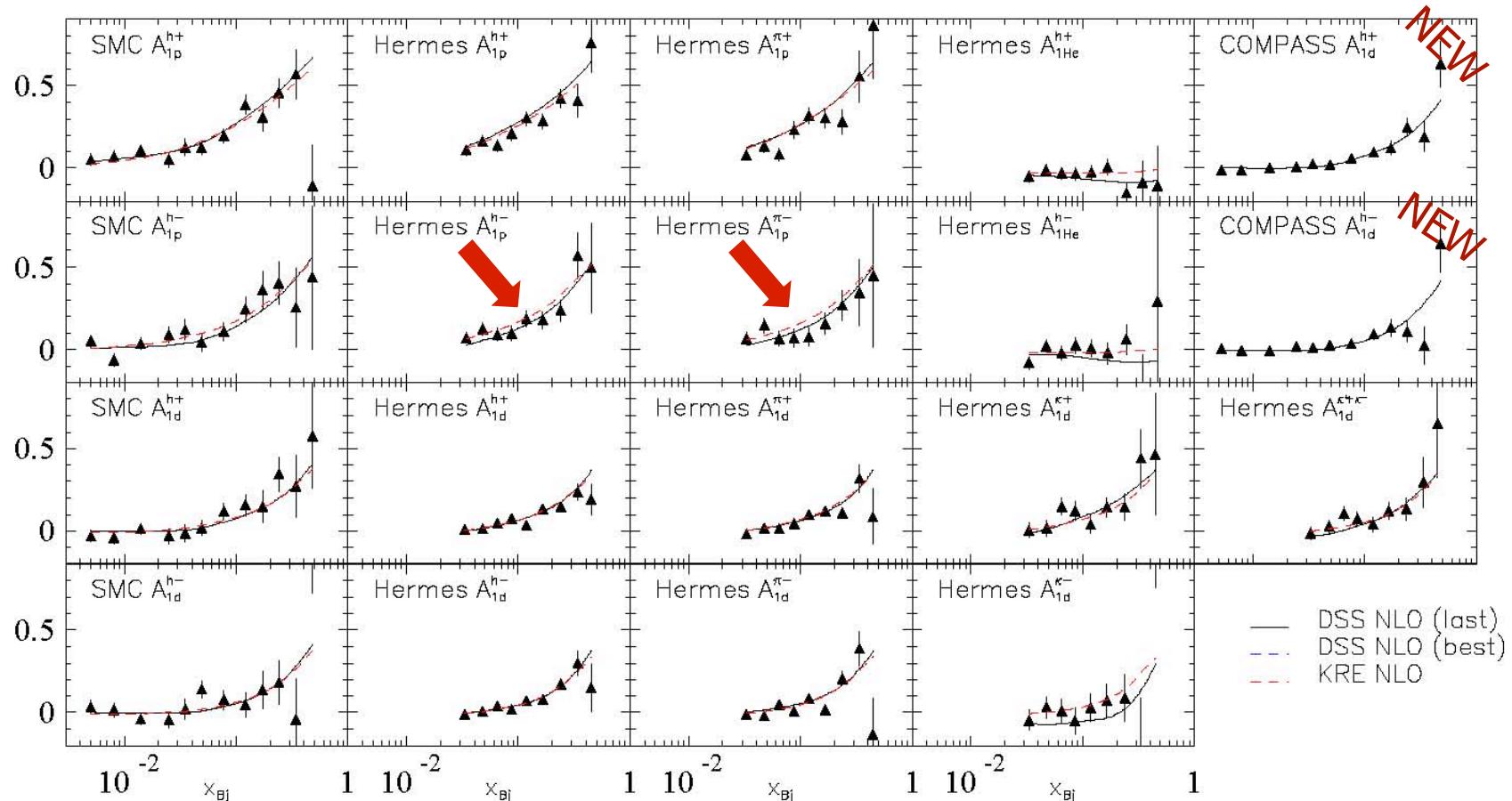
MSTW PDFs: positivity constraints, evolution

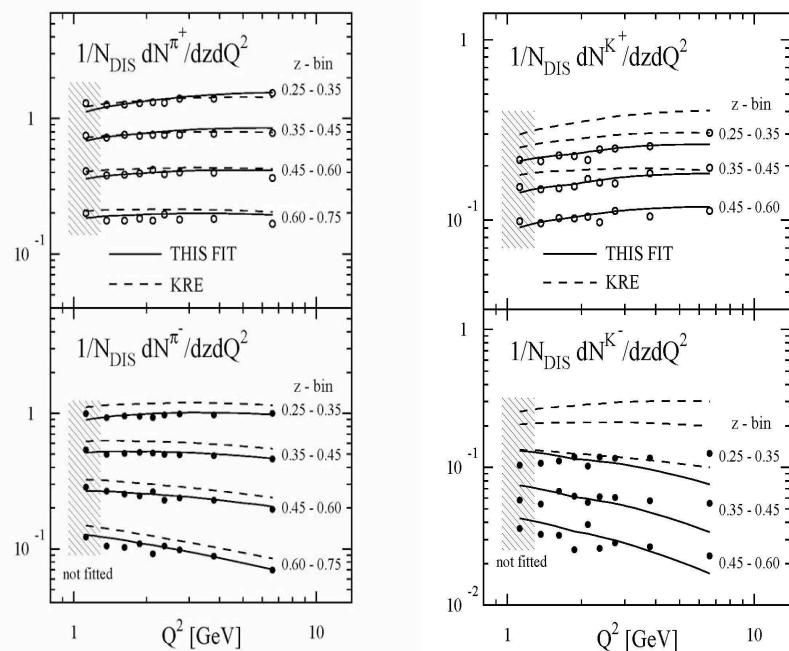
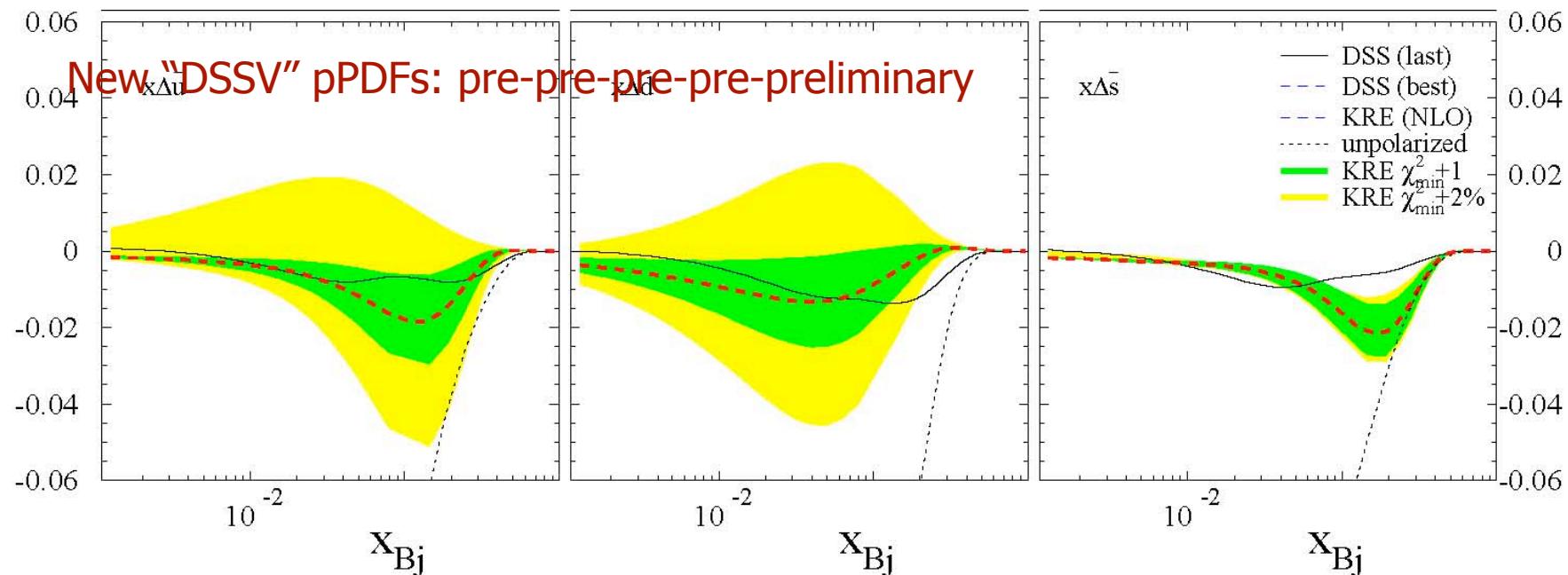
New Compass SIDIS data: flavor at low  $x$

Compass/Hermes DIS data (Q<sub>2</sub>-bin): gluon shape?

RHIC data:  $A_{LL}$ , jets:  $g$

## New “DSSV” pPDFs: pre-pre-pre-pre-preliminary....

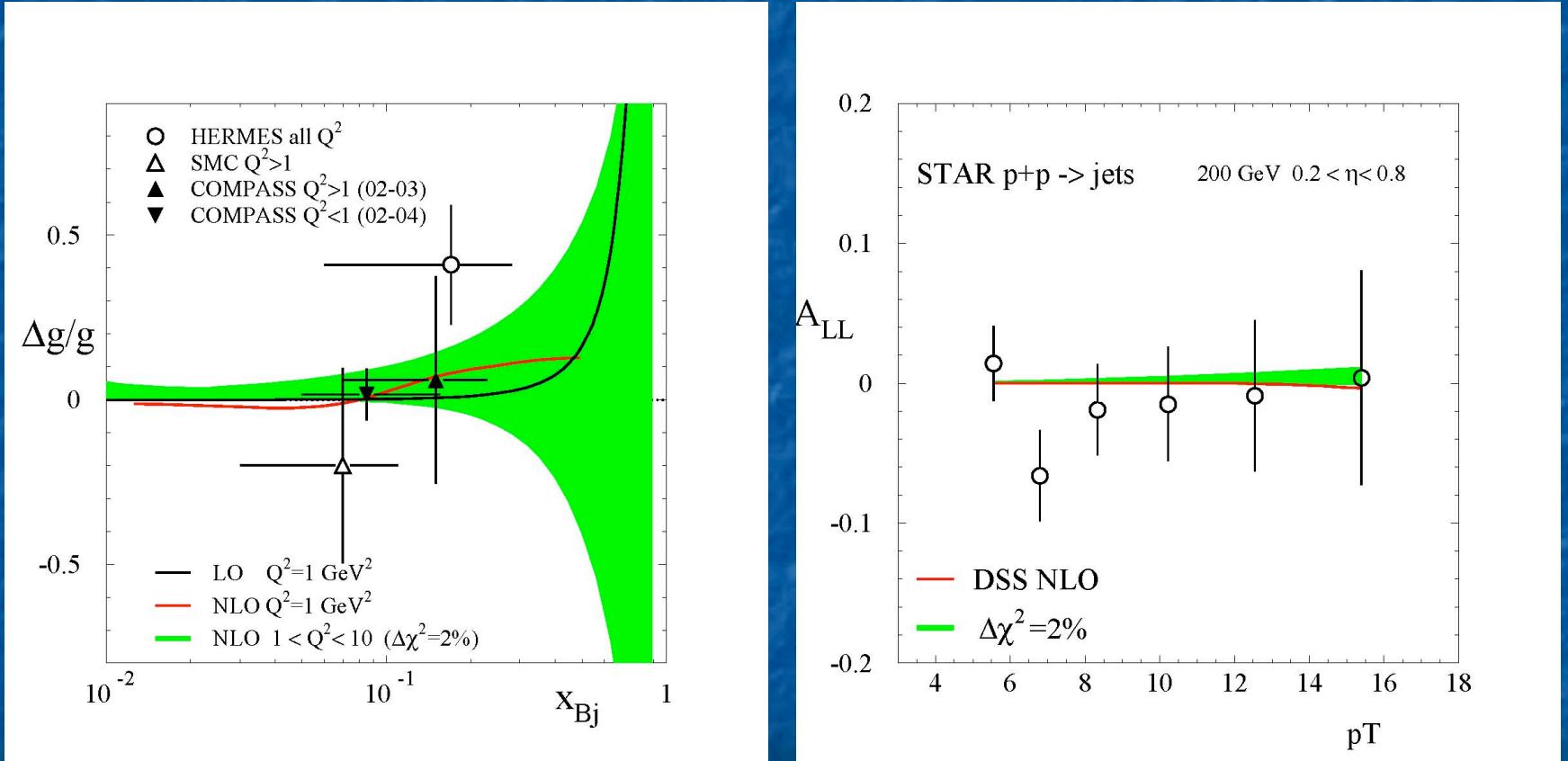




why has  $_s$  changed??

old FFs were overestimated

from Daniel's talk



## Conclusions:

- pPDFs have evolved dramatically:

successfull experimental programs  
tools for the analysis (NLO)  
from 'scenarios' to 'constraints'

- pSIDIS opens a window to sea quarks and helps to constrain other densities

consistency pDIS/pSIDIS  
improved constraints on pPDFs  
best fits favor small  $g_F$  and SU(3)?

- dependence on FFs as a caveat: needs improvement!

- future prospects: encouraging!

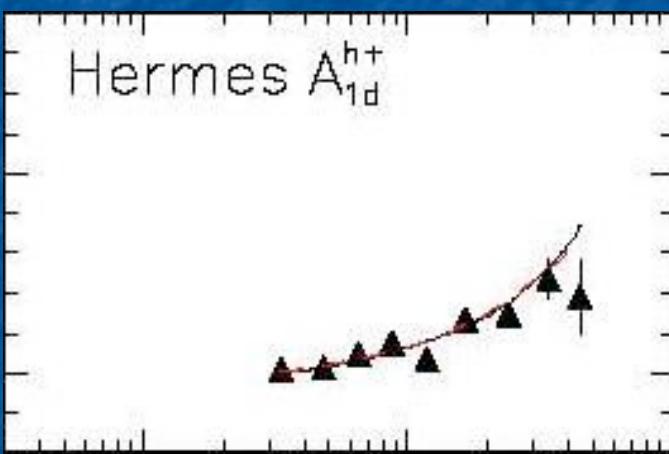
new polarized data: RHIC, COMPASS, JLAB, eRHIC?  
new generation of FFs  
most exciting in the spin saga:  
the unexpected...

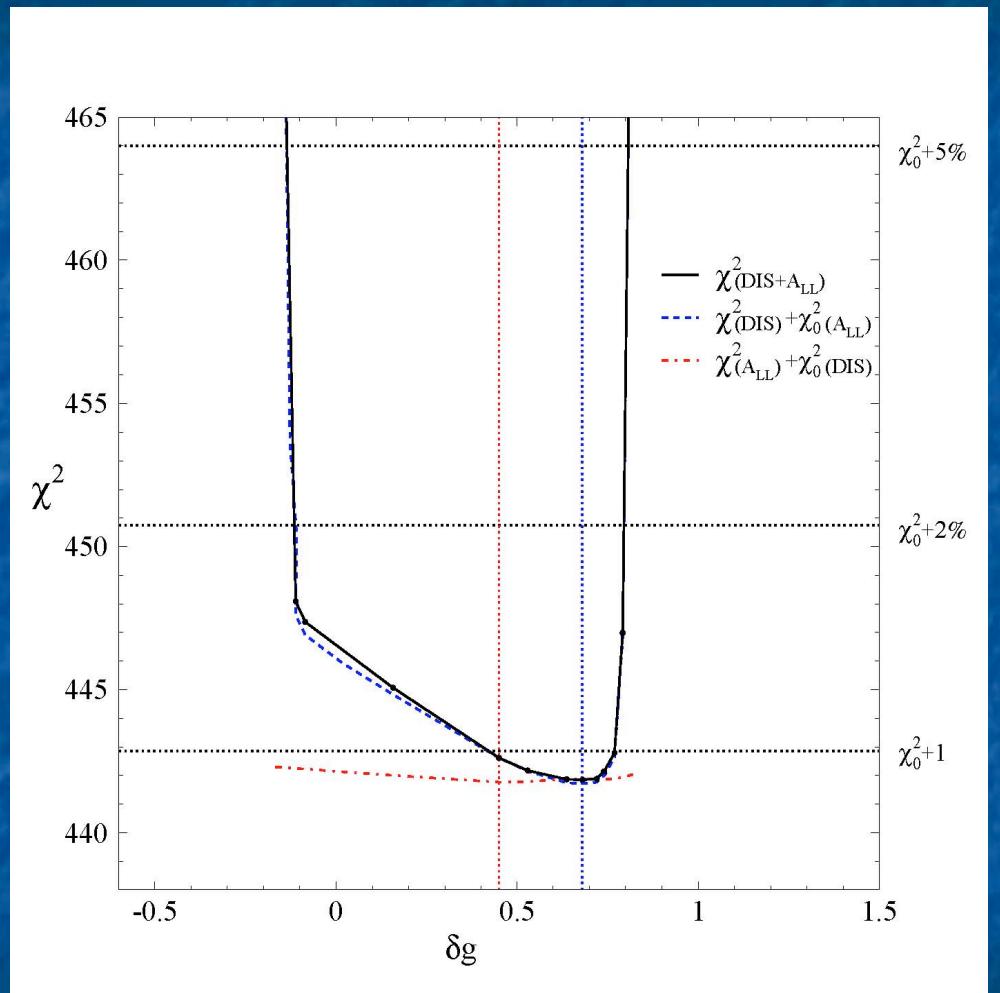
Acknowledgments:

A. Deshpande, W. Vogelsang

RIKEN-BNL, hospitality and support.







# Results:

D. de Florian, G. Navarro , R.S. Phys.Rev.D71 094018 (2005)



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Interplay be-

$$\chi^2 =$$

$$\Phi(\lambda, a_j) =$$

